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The Comparative Evaluation of Road Safety Developments in Greek Regions

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Abstract

Over the last decade, the number of fatalities in road crashes in Greece declined significantly, with the level of road safety differing among the various regions of the country. The objective of the study is to investigate the effects of transport and socioeconomic characteristics on road safety in the 13 Regions of Greece over the period 2004-2019. First, a cluster analysis was performed leading to four clusters: Islands, Western & Southern mainland, Northern mainland and Attica. Then, mixed linear models were developed for the whole country and for each of the clusters separately, in which the fatality rate per population was associated with transport and socio-economic indicators. The results depicted the different geographical characteristics, economic level, mobility patterns and road behaviors of the regions, which are also reflected in road safety outcomes.

Keywords: Road Safety; Crash Fatalities; Cluster Analysis; Linear Mixed Model; Greek Regions

1. Introduction

Road crashes are one of the leading causes of death worldwide. Road traffic injuries claim more than 1,35 million lives and more than 50 million injuries each year having a huge impact on public health and development (WHO, 2018). The European Union presents better road safety performance compared to other continents, due to targeted road safety policies and measures taken over the last decade at both national and regional level. Despite the good road safety performance, in 2020, the European Union did not manage to achieve the target of halving road crash fatalities compared to 2010. Within this context, the European Commission committed to improve the safety of the European road network. On that purpose, the EC has adopted a Road Safety Programme which aims to halve the number of road deaths and serious injuries by 2030, compared to the 2019 level (EC, 2019).

In 2020, Greece recorded 584 fatalities and 518 serious injuries in road crashes. Over the last decade, the number of fatalities and serious injuries in road crashes in Greece declined significantly by 54% and 70% respectively, as a

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result of systematic efforts made at national level, but also due to the economic recession over the period 2010-2018 (NRSO, 2021a). Despite the fact that Greece achieved the target of halving road crash fatalities during the decade 2010-2020, the total number of road crash casualties is still unacceptable, which intensifies the need for further efforts. Compared to the road safety performance of the European Union Member States, Greece in 2020 had the 20th position in terms of road crash fatalities per million population. In fact, Greece had 54 road fatalities per population while the European average was 42 fatalities per million population (NRSO, 2021b).

The level of road safety, however, is not the same in all regions of Greece. According to the Hellenic Statistical Authority (ELSTAT), in 2019, 998,8 crashes per million population occurred at national level. The Attica region (in which the capital city is included) was ranked first with 1,518.3 crashes, the South Aegean region had the second worst road safety performance with 1.258,6 crashes and in the third place was the North Aegean region with 1.004,1 crashes per million population. In terms of road crash fatalities, in 2019, 64,2 fatalities per million population were recorded in the country as a whole. Regarding this indicator, the South Aegean region had the worst road safety performance with 113,4 fatalities per million population, followed by the Peloponnese region with 106,2 and the North Aegean region with 90,5 (ELSTAT, 2019).

In this context, it is necessary to better understand the influence of the underlying factors affecting the road safety outcomes and identify the different road safety patterns among the Greek regions. The objective of the present study is to investigate the effects of transport and socioeconomic characteristics on road safety in the 13 Regions of Greece. For this purpose, data were collected for the 13 Regions of Greece over the period 2004-2019 on the number of road crash fatalities, population, vehicle fleet and socio-economic characteristics, such as the Gross Domestic Product (GDP) per capita, unemployment rates, tourist arrivals and available hospital beds. The main data source is the Hellenic Statistical Authority (ELSTAT), as well as Eurostat. The present study aims to better highlight the problem of road safety in Greece among the different regions, as well as to demonstrate the need to take into account demographic and socio-economic factors in the assessment of the evolution of road safety performance.

2. Literature Review

Several studies related to cross-country analyses of road safety have highlighted the influence of the socio-economic conditions on road crashes. In 1984, Wagenaar related the frequency of road crashes with the socio-economic effects and in particular with the unemployment rate for the US states, showing that 1% increase in unemployment rate leads to a reduction by 316 involved drivers in crashes over the same month and an increase by 237 involved drivers in road crashes over the following month. Further studies (Jacobs & Cutting, 1986; Söderlund & Zwi, 1995) identified the relationships between fatalities and injuries in road crashes and socioeconomic indicators (e.g. GDP per capita, population density, population per doctor, population per hospital bed) and transport related indicators (e.g. number of registered vehicles, road network density, share of registered vehicles per road network length or per population) using data for groups of countries (10 developed and 20 developing countries in the first study and 83 countries in the second study). Economic characteristics have been found to have strong influence in road crashes (Kopits & Cropper, 2005; Antoniou et al., 2016). Yannis et al. in 2014 used panel data for 27 EU countries for 35 years and showed that an annual increase of per capita GDP leads to an annual increase in road crash fatalities and vice versa.

Similar studies at regional or city level have also been conducted, with some indicators being differentiated depending on the different characteristics of the examined regions or cities. In 2013, Choustoulaki developed multilevel Poisson models associating the GDP per capita, urban population and vehicle fleet with road crash fatalities inside urban areas of 24 European countries. A similar study was conducted in 2015 (Yannis et al., 2015) in 9 European capital cities, with the city characteristics (road network length, population density, share of public transport use) having a strong relationship with crash characteristics (type of road user and type of involved vehicle in the crash). In 2019, Yannis et al. developed Generalized Linear Models associating economic (GDP per capita), demographic (population density), and mobility (road network density, number of registered motorcycles per population, public transport capacity and share of trips with bicycle) characteristics with road crashes for 25 European cities. At regional level, 101 EU NUTS-2 regions were benchmarked in terms of road safety performance, by taking into account road fatalities, demographic, economic and transport related indicators through Data Envelopment Analysis (DEA) (Folla et al., 2020).

Road safety studies at regional or city level in Greece are rather limited. In 2013, Spanakis explored the road crash characteristics of 30 Greek cities over the period 2006-2010, associating the existence of road median barrier, the existence of lighting on the roads, type of crash, type of involved vehicles, casualty age and vehicle fleet with the number of road crash fatalities, serious and slight injuries. In 2021, another study at regional level, showed that the number of crash fatalities per 100.000 population in Greek Regions is associated with the per capita income, number of vehicles in traffic, number of doctors, population density and unemployment, while the road safety performances of the Greek regions were benchmarked via DEA, taking into account the number of road crash fatalities, population, income and number of vehicles in traffic for each region (Michailoglou, 2021). Another study at regional level in Greece has also showed the influence of tourism on road crash fatalities, with the probability of tourists (Greek and foreigners) involved in road crashed being higher and the frequency of road crashes being increased in touristic regions over the touristic periods compared to the remaining Greek regions (Bellos et al., 2019).

3. Data Description

For the purposes of the current study, data on the number of road crash fatalities were collected for the 13 NUTS-1 regions in Greece over the period 2004-2019 from the Hellenic Statistical Authority (ELSTAT). Additionally, annual data for the same period were also collected from ELSTAT concerning the population, the number of all vehicles in traffic, the number of passenger cars in traffic, the number of motorcycles in traffic, as well as the number of tourist arrivals for each region. Annual GDP, unemployment rate, number of available doctors and hospital beds by region were extracted from Eurostat.

Figure 1 shows the evolution of the number of road crash fatalities by region for the period 2009-2014. In all regions, road fatalities present a clear decreasing trend over the whole period, which is more intense between 2008 and 2014 due to the economic recession in Greece, while a slight increase is observed in 2015 and 2016. After 2018, when the recession is over, the trend of fatalities varies depending the region. It is noted that 2020 has not been a representative year concerning road crashes in Greece, due to the COVID-19 pandemic and the related traffic restrictions imposed after March 2020, and as a result the related data have been excluded from the current analysis.

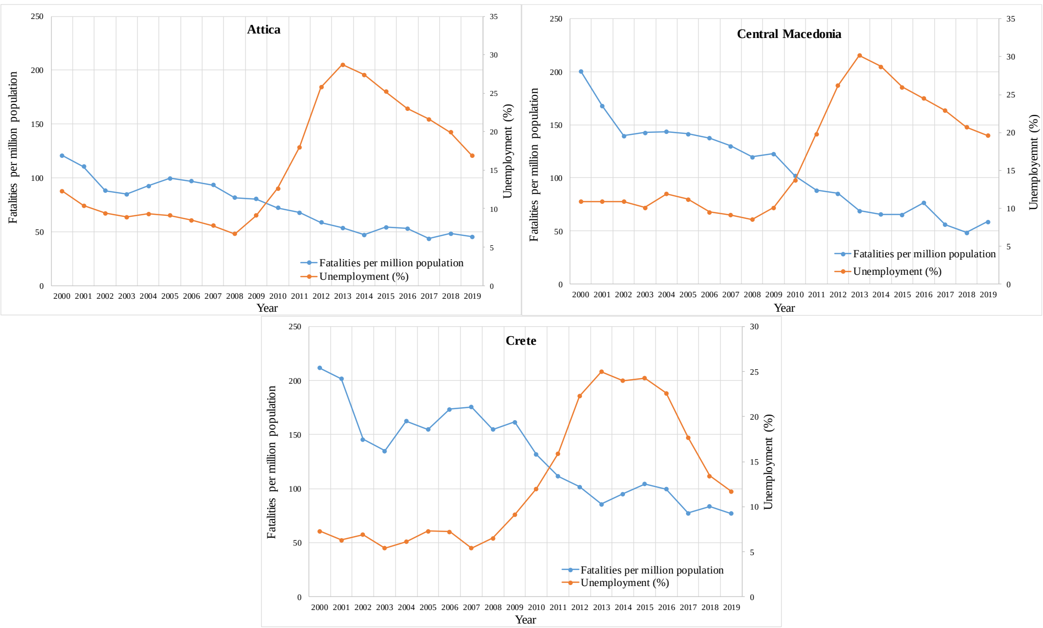

Figure 1. Evolution of road fatalities per population and unemployment rate in three Greek regions, 2004-2019

In Figure 1, the evolution of unemployment rate in comparison with road fatalities per million population is shown for three indicative regions: Attica (where capital city belongs), Central Macedonia (Northern Greece) and Crete (Southern Greece). It is observed that in all regions, the number of road fatalities per population decreases over the examined period, with the number of fatalities per population being lower in Attica compared to the other two regions. During the period 2004-2008, the unemployment rates have a steady and slightly declining trend in all examined regions, while a sharp increase is recorded from 2008 up to 2013, when it decreases again. However, the unemployment rates remain higher than the respective rates over the period before the economic recession (2004-2007). It is noted that the high decrease in road fatalities occurs between 2008 and 2014, when unemployment rates presents the highest increase.

In Figure 2, the evolution of the percentages of passenger cars and motorcycles in traffic in relation to the crash fatalities are shown for the same regions. Overall in Greece, over the last years, the number of passenger cars had a slightly increasing trend, with the percentage of motorcycles in traffic being more increased. This is mainly attributed to the economic crisis of the last years and citizens' preference for more economic means of transport.

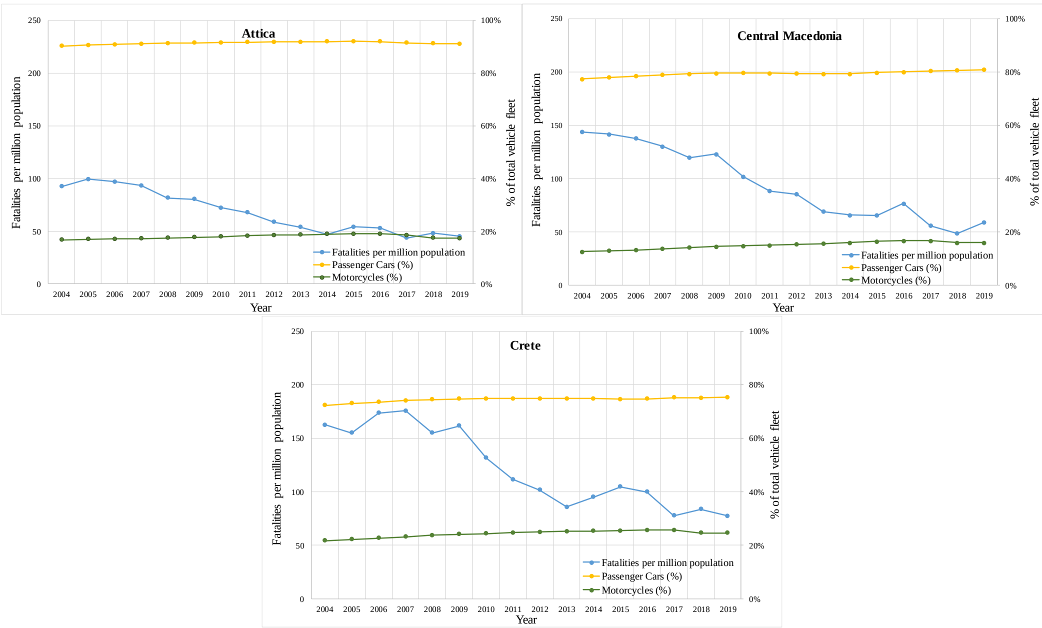

Figure 2. Evolution of road fatalities per population and percentages of passenger cars and motorcycles in total vehicle fleet in three Greek regions, 2004-2019

4. Methodology

4.1. Cluster Analysis

Cluster analysis is a technique used in data mining in order to discover underlying pattern in a dataset. Groups (clusters) are created on the basis of a chosen distance which is maximum among clusters and minimum within clusters. The two-step cluster algorithm developed in the present paper, at first runs a pre-clustering analysis, which examines the whole dataset in order to reduce the size of the matrix that contains distances between all possible pairs of cases. At this point, all cases in the same pre-cluster are treated as a single cluster. Then, the algorithm performs a hierarchical cluster on the pre-clusters.

The procedure is implemented by constructing a modified cluster feature (CF) tree, which consists of levels of nodes. The tree begins by placing the first case at the root of the tree in a leaf node that contains variable information about that case. Each successive case is then added to an existing node or forms a new node, based upon its similarity to existing nodes and using the distance measure as the similarity criterion, which is defined as the decrease in log-likelihood as a result of merging two clusters. A node that contains multiple cases is identified by a CF which comprises the statistical characteristics of the entry, and is defined as follows:

$$CFj = \{Nj, Mj, Vj, Kj\}, \qquad (2)$$

where Nj is the number of data records in Cj, Mj is the mean of each quantitative variable, Vj is the variance of each quantitative variable and Kj represents the counts for each category of each categorical variable. When two clusters Cj and Cs are merged, it means that two datasets of points become a single one, thus the CFjs of the new cluster is calculated by simply adding the corresponding entry in CFj and CFs, that is

$$CFjs = \{Nj+Ns, Mj+Ms, Vj+Vs, Kj+Ks\}. \qquad (3)$$

The process continues until a complete data pass is finished and pre-clusters are formed. In the second step, the agglomerative hierarchical clustering method groups the sub-clusters resulting from the previous step, according to the log-likelihood based distance measure.

4.2. Mixed Linear Model

Statistical analyses were carried out using the Linear Mixed Model (McLean et al., 1991). The Linear Mixed Models procedure expands the general linear model so that the data are permitted to exhibit correlated and non-constant variability. It, therefore, provides the flexibility of modeling not only the means of the data but their variances and covariances as well. Linear Mixed Models' mathematical relation in matrix form is the following:

$$y = X\beta + Zu + \varepsilon \qquad (1),$$

Where:
y is a N×1 column vector, the outcome variable;
X is a N×p matrix of the p predictor variables;
β is a p×1 column vector of the fixed-effects regression coefficients (the βs);
Z is the N×q design matrix for the q random effects (the random complement to the fixed X);
u is a q×1 vector of the random effects (the random complement to the fixed β);
ε is a N×1 column vector of the residuals, that part of y that is not explained by the model, Xβ+Zu.

5. Results

5.1. Cluster Analysis

A two-step cluster analysis was performed in order to group regions with similar characteristics in wider groups. For the cluster analysis, 6 inputs were considered, mainly demographic, socio-economic and transport related characteristics of the regions that are also associated with road safety outcomes. The six input variables on which the final clusters were based are: the population density of region (in inhabitants per km^2), percentage of passenger cars in total vehicle fleet, percentage of motorcycles in total vehicle fleet, the ratio of foreign tourist arrivals per the total number of tourist arrivals, available hospital beds per population and the per capita GDP of each region.

Based on these characteristics, the following four clusters were defined, with an average silhouette measure of cohesion and separation equal to 0,6 (Figure 3):

- Cluster 1 (Islands): Ionian islands, Crete, South Aegean, North Aegean;
- Cluster 2 (Western and Southern mainland): Western Greece, Peloponnese, Central Greece;
- Cluster 3 (Northern mainland): East Macedonia & Thrace, Western Macedonia, Central Macedonia, Thessaly, Epirus;
- Cluster 4: Attica.

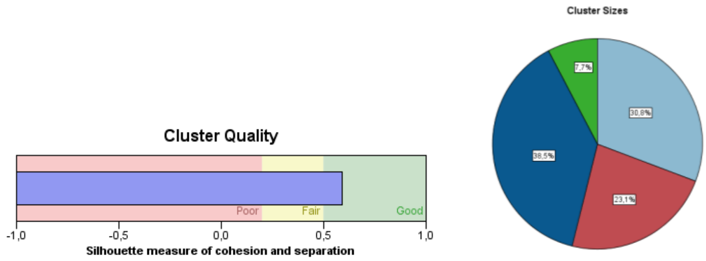

Figure 3. Two-step cluster analysis results

5.2. Mixed Linear Models

In the context of this statistical analysis, the dependent variable was the mortality rate in road crashes, expressed as the natural logarithm of the number of fatalities in road crashes per million population. Mortality rate was correlated with the unemployment rate of each region, the natural logarithm of the number of motorcycles in traffic per thousand population, the percentage of passenger cars in total vehicle fleet and the available hospital beds per thousand population within each region. In the present study, panel data with repeated observations for each cluster of regions were analyzed, thus, Mixed Linear Models were selected as the most appropriate methodology. All explanatory variables in the models were considered as fixed effects. Consequently, four models were developed: the first includes all regions of Greece, with the clusters of the regions based on the results of the cluster analysis being considered as independent variables and three additional models per cluster. It is noted that for the cluster of Attica, no model was developed due to the small size of the respective database.

The results of the statistical models are presented below for all regions (Table 1) and for each cluster of regions (Table 2). Moreover, it is noted that elasticities for the independent variables have been calculated, enabling also comparisons among the different variables of each model.

Table 1. Mixed Linear Model for mortality rate in all Greek regions

Parameter	Coefficient	t-test	Sig.	e_i
Intercept	5,064	8,215	0,000	-
Cluster 1	0,759	5,499	0,000	-
Cluster 2	1,062	5,999	0,000	-
Cluster 3	0,533	4,615	0,000	-
Cluster 4	0	.	.	-
Unemployment (%)	-0,040	-16,166	0,000	-0,146
LN(Motorc/pop)	-0,196	-3,01	0,003	-0,200
PassengerCar (%)	0,015	2,705	0,008	0,179
HospitalBeds/pop	-0,054	-2,037	0,043	-0,045
-2 Restricted Log Likelihood	17,728			

The results of the statistical models (Table 1 and Table 2) have shown that:

- The unemployment rate has a negative relationship with the dependent variable, showing that as unemployment increases, the mortality rate in road crashes decreases.
- An increase in the rate of motorcycles per population is associated with a decrease in the fatality rate per population.
- The percentage of passenger cars in total vehicle fleet is positively correlated with the number of road fatalities per population, meaning that an increase of the passenger cars in traffic lead to more road crash fatalities, with this effect being higher for the islands.

- The ratio of available hospital beds per population is negatively associated with the traffic fatalities in all regions, with the highest effects of this indicator being identified in the regions of Northern mainland Greece.
- The number of fatalities per population in all clusters of regions is higher than the respective number of fatality rates in Attica, with the highest difference being identified for Western and Southern mainland Greece.

Table 2. Mixed Linear Models for mortality rate per cluster of regions

	Cluster 1 (Islands)				Cluster 2 (Western & Southern mainland)				Cluster 3 (Northern mainland)			
Parameter	Coefficient	t-test	Sig.	e_i	Coefficient	t-test	Sig.	e_i	Coefficient	t-test	Sig.	e_i
Intercept	3,095	9,436	0,000	-	7,980	7,777	0,000		8,776	8,056	0,000	
Unemployment(%)	-0,032	-12,396	0,000	-0,098	-0,022	-3,733	0,001	-0,076	-0,046	-10,602	0,000	-0,189
LN(Motorc/pop)	-0,136	-2,213	0,053	-0,154	-0,862	-3,865	0,000	-0,780	-0,374	-3,363	0,001	-0,359
PassengerCar(%)	0,060	48,581	0,000	0,627	0,017	2,025	0,049	0,156	-0,018	-1,533	0,130	-0,237
HospitalBeds/pop	-0,037	-7,588	0,000	-0,028	-0,240	-3,222	0,002	-0,118	-0,133	-2,348	0,021	-0,132
-2 Restricted Log Likelihood	-15,578				4,997				35,296			

6. Conclusions

Greece is a country which presents several geographical peculiarities, with many islands, but also several mountainous areas in mainland Greece. The different extent and geographical characteristics of the various Greek regions as well as their different economic activities are reflected in different mobility patterns and road behaviors among the inhabitants of these regions, but also in a different degree of development of the road network, readiness of emergency services, hospital staffing, etc. and consequently in road safety outcomes. The economic recession of the last years (about 2008-2018) has also affected the various regions of Greece to a different degree, having also different impact on the road safety progress in these regions.

In this context, there is a need to identify and better understand the different road safety patterns among the Greek regions. The objective of the present study is to investigate the effects of transport and socioeconomic characteristics on road safety in the 13 Regions of Greece. For this purpose, data were collected for the 13 Regions of Greece over the period 2004-2019 on the number of road crash fatalities, demographics, vehicle fleet and socio-economic characteristics. First, a cluster analysis was performed leading to four clusters: Greek islands, Western & Southern mainland, Northern mainland, Attica (where capital city belongs). These clusters reflect the different geographical and demographic characteristics (in terms of population density) of the regions, the mobility opportunities and preferences of inhabitants (greater network of public transport in capital city vs greater use of passenger cars in mountainous areas and greater use of motorcycles in islands and lowland areas), as well as the different economic level and cultural habits.

Then, mixed linear models were developed for the whole country and for each of the clusters separately, in which the fatality rate per population was associated with transport and socio-economic indicators. The analysis showed that the increase in unemployment led to a decrease in the number of fatalities in road crashes, highlighting the effect of economic recession in road safety outcomes, with effect of the unemployment on road safety being higher in Northern mainland Greece. Additionally, a positive relationship was identified between the number of motorcycles in traffic and road fatalities. This result does not essentially express a causal relationship, but rather reflects the situation of recent years in all regions of Greece, where there has been a significant reduction in road fatalities due to economic crisis and a shift towards more economic means of transport and shorter trips. Additionally, the increase of passenger cars in vehicle fleet leads to a higher increase in road fatalities in islands, which is mainly attributed to the increase of traffic in these regions for almost half of the year (during the touristic period), mainly from tourists who are either not familiarized with the existing road environment or present a more unsafe behavior (increased drink-driving, more young drivers, more vulnerable road users, etc.). Finally, since data on emergency response time at regional level are not available, the availability of hospital beds per population was used a proxy of post-crash care level, indicating that regions with lower available hospital beds per population present increased road crash fatalities.

In conclusion, the present study aims to better highlight the problem of road safety in Greece among the different regions, as well as to demonstrate the need to take into account demographic and socio-economic factors in the assessment of the evolution of road safety performance.

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